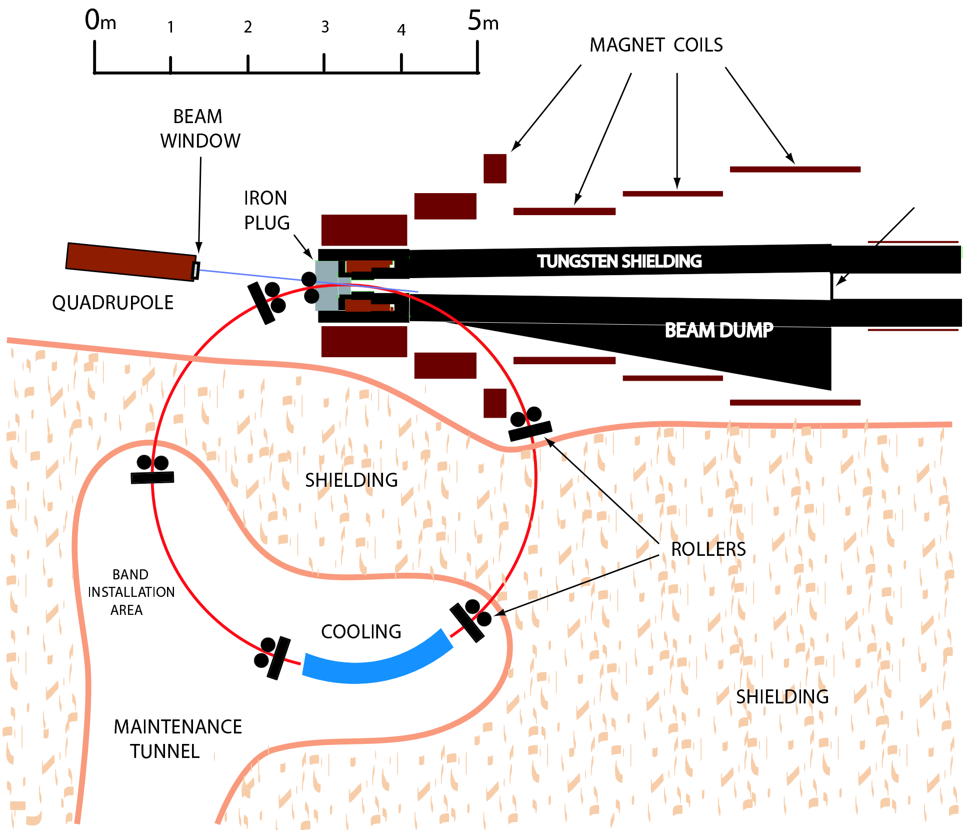

Figure 1: A conceptual illustration of the targetry setup.

1 Rotating Inconel Band Option for the Pion Production Target

1.1 Introduction and Overview

As a back-up scenario to the base-line mercury jet target design, this appendix presents a solid-target option that is based around an Inconel Alloy 718 target in a rotating band geometry. Similar conceptual designs for rotating band targets have been presented previously [1, 2, 3], for use at both muon colliders and neutrino factories, and a more detailed description of this particular conceptual design can be found in reference [4].

A plan view of the targetry setup for the band target option is shown in figure 1. An inconel target band threads through the solenoidal magnetic capture channel to tangentially intercept the proton beam. The circulating band is cooled by passage through a water tank located in a radiation-shielded maintenance enclosure.

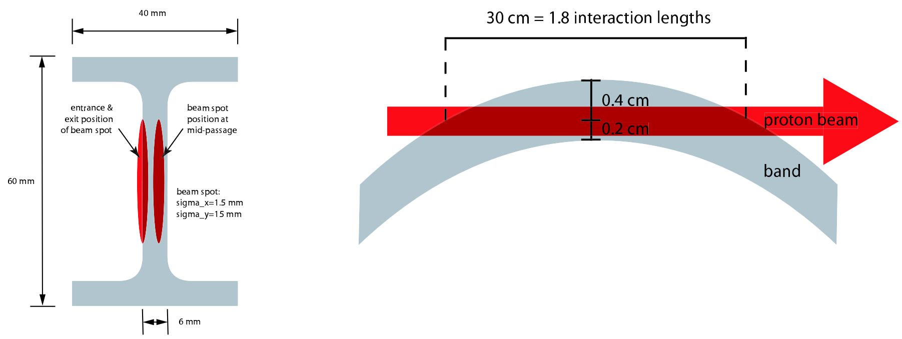

Figure 2: Passage of the proton beam through the target band shown in cross-sectional (left) and plan (right) views. The horizontal position of the beam spot in the band webbing varies along the interaction region due to the curvature of the band. The plan view shown in the right plot has a very distorted 10:1 aspect ratio.

Inconel 718 is a niobium-modified nickel-chromium-iron superalloy that is widely used in nuclear reactors and particle accelerator applications because of its high strength, outstanding weldability, resistance to creep-rupture due to radiation damage and to corrosion from air and water. The inconel target band has an I-beam cross section. The band dimensions and positioning relative to the proton beam are shown in figure 2. The proton pulse structure and bunch charges were assumed to be identical to the base-line scenario with a mercury jet target. A tabulation of geometrical parameters for the inconel target, and of the assumed parameters for the incident proton beam, is provided in table 1.

Table 1: Specifications of the inconel target band and assumed proton beam parameters.

target band radius (R)	2.5 m
band thickness (t)	6 mm
band webbing height (h)	60 mm
full width of band flanges	40 mm
beam path length in band (L)	30 cm
proton interaction lengths (λ)	1.81
band rotation velocity (v)	1 m/s
proton energy	24 GeV
protons/bunch	1.7×10^{13}
bunches/fill	6
time between extracted bunches	20 ms
repetition rate for fills	2.5 Hz
horizontal beam-channel angle (α)	100 mrad
rms beam spot size at target	1.5 mm (horizontal) 15.0 mm (vertical)

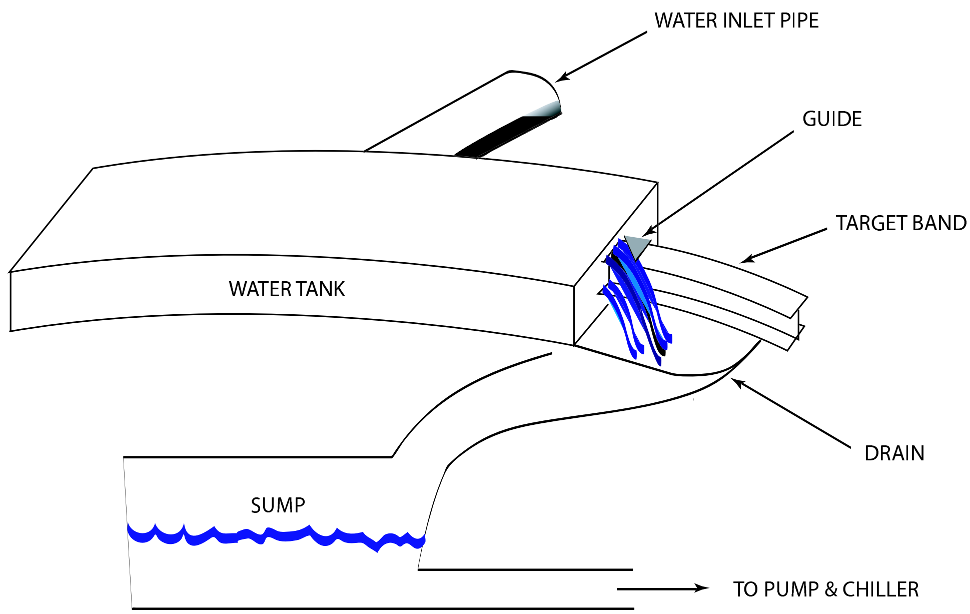

Figure 3: A conceptual illustration of the target cooling setup.

1.2 Mechanical Design Considerations

As is evident from figure 1, the threading of the target band through the pion capture channel represents only a slight variation on the channel design for the base-line mercury jet target option. The band entry port need only traverse the iron plug in the upstream end of the capture solenoid while the downstream port traverses the tungsten shielding and then passes between the solenoidal magnet coil blocks and out of the pion decay channel. Two plausible options for incorporating the exit port into the magnet cryostat are discussed in reference [4]. The third coil block downstream from the upstream end had to be moved outwards by approximately 10 centimeters to provide adequate space for the band to exit the channel. A modest re-optimization of the coil currents was required to restore the magnetic field map in this region to the base-line specifications.

No detailed consideration has yet been given to the design of the beam dump. As is clear from figure 1, the target band exit port is far enough upstream from the beam dump for it to be not a relevant factor in the beam dump design.

The band is guided and driven by several sets of rollers located around its circumference, as is shown in figure 1. A few hundred watts of drive power [4] should be required to overcome the eddy current forces from the band entering and exiting the 20 tesla solenoid. and the smaller drag forces from the water in the cooling tank. Following the lead of the BNL g-minus-2 target design, the roller assemblies will all incorporate self-lubricating graphalloy [5] bushings that are compatible with high radiation environments.

The pion production region of the target and its surrounds are in an air environment, with beam window positions shown in figure 1. Activated air and gases from the target and interaction region are continuously diluted and then vented from the target hall into the outside atmosphere following the procedure adopted for the BNL g–2 target.

The heated portion of the band rotates through a 2 meter long cooling tank [4] whose conceptual design is shown in figure 3. The band entrance and exit ports in the ends of the tank also serve as the water outlets. Both the heat transfer rates and water flow rates are found [4] to be relatively modest and the water flows due to gravitational pressure alone with no anticipated need for forced convection.

The number of incident proton bunches on any particular section of the rotating band, and hence the localized radiation damage, is reduced by a factor of approximately 50 relative to a fixed target geometry. Hence, each target band may last for several years [4] before requiring replacement.

The heavily irradiated used bands will be remotely extracted in pieces by progressively clamping then shearing off 1 meter lengths and dropping them into a hot box. After removal of the hot box, the band maintenance area can then be accessed and the new band progressively installed by welding together, in situ, eight 1.96 meter long chords of target band that have been previously cast (or otherwise prepared) into the correct I-beam cross section and circumferential curvature. Beam-induced stresses on the welds are minimized by welding on the flanges of the I-beam rather than on the central webbing that is exposed to the proton beam and to much larger energy depositions.

1.3 Simulations of Pion Yields and Beam-Induced Stresses

Full MARS [6] tracking and showering Monte Carlo simulations were conducted [4] for 24 GeV protons incident on the target, returning predictions for the pion yield and energy deposition densities.

The yield per proton for pions-plus-kaons-plus-muons at 70 cm downstream from the central intersection of the beam with the target was determined [4] to be 0.715 (positive) and 0.636 (negative) for the momentum range $0.05 < p < 0.80$ GeV/c, and 0.304 (positive) and 0.288 (negative) for the kinetic energy range $32 < E_{kin} < 232$ MeV that approximates the capture acceptance of the entire cooling channel. This is slightly lower than the yield from a mercury target; for the identical geometry, hypothetically replacing inconel with mercury was found to increase the yield by 15%.

Approximately 7% of the proton beam energy is deposited in the target as heat, with a maximum instantaneous heat rise of approximately 30 degrees centigrade from a single proton bunch. Detailed 3-dimensional maps of energy deposition densities were generated for input to dynamic target stress calculations [4] using the commercial ANSYS finite element analysis code.

The ANSYS simulations conservatively assumed the deposited energy to all be converted to an instantaneous local temperature rise. The von Mises stress (i.e. the deviation from the hydrostatic state of stress) was found to be initially zero but to develop and fluctuate over time as the directional stresses relax or reflect from material boundaries. The predicted 200 MPa peak value for the von Mises stress from a single proton bunch is approximately a factor of six below the yield strength for inconel 718 and well below its fatigue strength.

The band rotation speed, 1 m/s, advances the band by 40 cm between successive beam fills. This presents a fresh 30 cm chord of target band for each beam fill but the energy depositions from the 6 bunches within the fills are largely superimposed. However, the pile-up of stresses is not considered serious since any significant level of von Mises stress is expected to die out well within the 20 millisecond time span between successive bunches, leaving only the relatively benign hydrostatic stresses. This prediction could not be fully verified due to computational limitations but the general trend of reduction in von Mises stresses was tentatively confirmed in ANSYS calculations that simulated a time span of only several microseconds.

1.4 Conclusions

In summary, the inconel rotating band target design appears to be a promising back-up option to the base-line mercury jet target. The pion yield appears slightly lower than the mercury base-line, although this has yet to be fully optimized. The engineering design looks manageable and initial simulations of target stresses are encouraging.

References

[1] *A Cupronickel Rotating Band Pion Production Target for Muon Colliders*, B.J. King *et al.*, Proc. PAC'99, IEEE, pp. 3041-3.

[2] *Rotating Band Pion Production Targets for Muon Colliders and Neutrino Factories*, B.J. King, NIM A 451 (2000) pp. 335-343, Proc. ICFA/ECFA Workshop "Neutrino Factories based on Muon Storage Rings (nuFACT'99)", physics/0005007.

[3] *Some thoughts on a high-power, radiation cooled, rotating toroidal target for neutrino production*, J.R.J. Bennett, NIM A 451 (2000) pp. 344-348, Proc. ICFA/ECFA Workshop "Neutrino Factories based on Muon Storage Rings (nuFACT'99)".

[4] Muon Collider Note in preparation.

[5] Graphalloys are manufactured from molded graphite impregnated with metal. Graphalloy is a registered trademark of the Graphite Metallizing Corporation.

[6] N.V. Mokhov, "The MARS Code System User's Guide", Fermilab-FN-628 (1995). N.V. Mokhov and O.E. Krivosheev, "MARS Code Status", Fermilab-Conf-00/181 (2000). http://www-ap.fnal.gov/MARS/ .